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Comparison of the Size of ADF Aircrew and US Army Personnel

Peter Blanchonette[1] and Adrian Smith[2]

[1]Aerospace Division
Defence Science and Technology Organisation

[2]Institute of Aviation Medicine
Royal Australian Air Force

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ABSTRACT

Most aircraft that the Australian Defence Force (ADF) acquire are designed using anthropometric data from overseas populations. Often, the 1988 US Army dataset is used. A comparison of the size of ADF aircrew and US Army personnel showed that there were significant differences in the size and shape of the two groups. Given these size differences, vehicles designed using the US Army dataset may result in suboptimal accommodation rates for ADF aircrew. The ADF aircrew dataset has a number of issues which limit its use. It is recommended a comprehensive survey of aircrew is conducted.

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Comparison of the Size of ADF Aircrew and US Army Personnel

Executive Summary

Most aircraft that the Australian Defence Force (ADF) acquire are designed using anthropometric data from overseas military populations, and for many acquisitions the aircraft's design has been guided by United States (US) military anthropometric data. The most recent large scale survey of a US military population for which the data is readily available was conducted in 1988. The survey, commonly referred to as ANSUR, took over 130 measurements on over 9000 personnel based across the United States. Anthropometric specifications have been developed for many items of clothing, equipment and vehicles using the ANSUR dataset (or a subset) such as the Comanche helicopter and the Joint Strike Fighter. The most recent survey of the ADF aircrew population was conducted in 2004-5 as part of Project MIS 872. In total, over 200 ADF aircrew were measured at a number of bases using a combination of traditional manual techniques and three dimensional laser scanning.

Given the ANSUR dataset, or a subset of the dataset, is often used to support the design of clothing, vehicles and equipment, the goal of this report was to compare the size and proportions of ADF aircrew and ANSUR subjects. Following a comparison of the protocols used for the two surveys and the availability of equations to convert between different protocols and digital and manual measurements, it was found that six measurements and three proportions were comparable. These dimensions, including stature, waist circumference and sitting height, largely described the size and proportion of the two groups.

A comparison of the size and proportions of the ADF aircrew and US Army personnel found that there were some significant differences in the size and shape of ADF aircrew and US Army personnel. The Australian aircrew were on average taller, heavier and had longer torsos. The ADF aircrew also had larger waists and hips and a larger sitting height/stature ratio. Given these size differences, vehicles designed using the ANSUR dataset may result in suboptimal accommodation rates for ADF aircrew.

The MIS 872 survey was completed eight years ago and may not accurately reflect the size and shape of current aircrew. Furthermore, the anthropometric dataset has a number of shortcomings which limit its use. Given the increasing size of aircrew and the shortcomings of the existing data, it is recommended a comprehensive anthropometric survey of aircrew be conducted to ensure aircrew accommodation is maximised for future acquisitions.

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Authors

Peter Blanchonette
Air Operations Division

Peter Blanchonette is a Senior Research Scientist in Aerospace Division. He joined DSTO in 1995 after completing a PhD at Monash University. During his time at DSTO Peter has worked in a diverse range of areas including anthropometry, human in the loop simulation, helmet mounted displays, ergonomics, task network modelling and operations research.

Adrian Smith
Institute of Aviation Medicine

Dr Adrian Smith is the Head of Research for the Royal Australian Air Force Institute of Aviation Medicine. He has worked in aviation medicine research for more than 10 years, including extensive work on aircrew anthropometry and cockpit accommodation of ADF aircrew. His postgraduate qualifications in aerospace medicine include the Diploma in Aviation Medicine form the Royal College of Physicians (London) and a Masters in Aerospace Medicine (with Honours). He is a Member of the International Academy of Aviation and Space Medicine, and a Fellow of the Australasian College of Aerospace Medicine, the Aerospace Medical Association, and the Royal Aeronautical Society.

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Glossary

ADF	Australian Defence Force
ANSUR	ANthropometric SURvey
CAESAR	Civilian and American Surface Anthropometry Resource
ISAK	International Society for the Advancement of Kinanthropometry
NHANES	National Health And Nutrition Survey
MOTS	Military Off-the-shelf
US	United States

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1. Introduction

The three branches of the Australian Defence Force (ADF) operate a number fixed- and rotary-wing aircraft types. The Royal Australian Air Force (RAAF) operates 14 different manned aircraft types, including the C-130J Hercules, F/A-18F Super Hornet and C-17 Globemaster. The Army operates five different rotary-wing aircraft types, the OH-58 Kiowa, CH-47 Chinook, S-70A-9 Black Hawk, MRH 90 Taipan and ARH Tiger. Finally, the Royal Australian Navy (RAN) operates three rotary-wing aircraft types, the S-70B-2 Seahawk, MRH 90 Taipan and AS 350BA Squirrel. Ideally, each aircraft that the ADF acquires should be designed to maximise the accommodation of the current and potential aircrew populations (ensuring aircrew can reach all the controls, maintain clearance with the aircraft structures and maintain an appropriate internal and external field of view).

Typically, aircraft that the ADF acquire are Military Off-the-shelf (MOTS) procurements, with the human machine interface designed using anthropometric (body size) data representative of one or more overseas military populations. Often United States (US) military anthropometric data is used to guide the design of the aircraft cockpit and cabin as the US military is the prime customer for many acquisitions and anthropometric data is readily available for the US military. The most recent large-scale anthropometric survey of the US military population for which the data is freely available was conducted in 1987-88. The survey, commonly referred to as ANSUR (which stands for ANthropometric SURvey), took more than 130 manual measurements on over 9000 male and female US Army personnel at 11 US Army posts (Gordon et al., 1989). Measurements taken included stature, mass, sitting height, waist circumference and interpupillary breadth. A subset of this dataset, selected to represent the demographic distribution of the US Army, is often used to support the design of clothing, equipment and vehicles, such as the redesign of the Comanche helicopter (Kozycki and Gordon, 2002). A subset of this dataset was also used to represent the pilot population for the Joint Strike Fighter (Zehner, 2009).

The most recent anthropometric survey of ADF aircrew was conducted in 2004 and 2005 as part of Project MIS 872 (Olds et al., 2007, Singh and Smith, 2008). Over 200 aircrew were manually measured using traditional anthropometric techniques. Aircrew were also scanned in a standing posture using a three dimensional laser scanner, capturing a digital statue of each subject. Specialised software was then used to extract measurements from the scans. In addition to traditional measurements such as lengths and breadths, volumes, surface areas and cross sections can also be extracted from the scans.

Given most ADF aircraft acquisitions are MOTS and are potentially designed using US data, the goal of this report was to compare the size, shape and proportion of the ADF aircrew surveyed in MIS 872 with the US Army personnel measured in ANSUR and determine if there are any significant differences[1]. This report will help inform future acquisitions of clothing, equipment and vehicles which have been designed and developed based on the ANSUR anthropometric dataset.

[1] As less than ten females were measured as part of MIS 872, only males will be compared in this report.

2. Method

2.1 ADF Aircrew Survey

Project MIS 872 surveyed a sample of the potential recruit population (civilian males and females 18-30 years old, who have passed year 12) and current aircrew during 2004 and 2005 (Olds et al., 2007, Singh and Smith, 2008). The purpose of the survey was to develop a database that could be used to support the design and acquisition of clothing, equipment and aircraft. To ensure the survey captured an appropriate cross-section of young Australians, the survey team measured volunteers in Perth, Adelaide, Melbourne, Canberra, Sydney and Brisbane. In total, they measured 1510 male and female civilians. In addition, they visited a number of RAAF bases: Williamtown, Edinburgh, Amberley, Richmond and Pearce and measured 255 aircrew (including nine female aircrew). Unlike previous Australian surveys, in which the measurements were only taken manually using anthropometers, callipers and tape measures, this survey also used a three-dimensional laser scanner to capture a digital "statue" of the subjects. Four measurements, stature, sitting height, buttock-knee length and mass were taken manually (due to the difficulty the system had detecting horizontal surfaces and the volume the system could scan). Using specialist software, traditional measurements, such as girths, could be extracted from the scans. Thirty-seven measurements are available for most of the subjects, including stature, mass, waist and hip circumference, biacromial breadth, foot length and radiale-stylion length.

2.2 ANSUR Survey

The US Army surveyed 5,506 male and 3,491 female personnel in the late 1980s (Donelson and Gordon, 1991)[2]. Prior to this survey, the last survey of males had been conducted in 1966 and females in 1977. Given the change in the racial and age profiles of the US Army during the intervening years, along with the secular trends in body size, it was necessary to update the datasets for both sexes. The survey was conducted at 11 US Army posts during a 12 month period in 1987 and 1988. The subjects were chosen to match both the age and race profiles of the US Army. A diverse range of 132 measurements were taken manually by a team of 22 measurers, along with 26 three-dimensional co-ordinates of the head and face. It took approximately four hours per subject to collect all the measurements (Paquette, 1996). The measurements were chosen to support the design of clothing, equipment, and workstations, along with the sizing of mannequins for human modelling software. A diverse range of equipment was used to capture the anthropometric dimensions, including a steel tape, pupillometer (for interpupillary distance), sliding callipers and foot box. The measurements taken included standard measurements such as buttock-knee length, waist circumference and sitting height, and less common

[2] DSTO has a subset of this dataset referred to as the ANSUR working database.

measurements such as overhead finger tip reach, sitting wrist height, and knee circumference. Along with the anthropometric measurements, a range of demographic data was also gathered, including age, rank, and ancestry.

2.3 Protocol Comparison and Measurement Selection

There are many anthropometric protocols in common use today, including the International Society for the Advancement of Kinanthropometry (ISAK), Civilian American and European Surface Anthropometry Resource (CAESAR) and ANSUR, which have their origins in a numbers of fields, including sports science and ergonomics. Each of these protocols has developed its own set landmark sites (typically bony points on the body) and measurement definitions. So, in many cases, the measurement definitions and landmarks used by different protocols are very similar but not identical. For example, there are several different measurement definitions for stature, which can result in this measurement varying by up to two centimetres. The MIS 872 survey followed a combination of the ISAK and CAESAR protocols, and with the exception of four measurements (stature, mass, sitting height, buttock-knee length and mass), all of the measurements were taken digitally. In contrast, the US Army 1988 survey used the ANSUR protocol and all measurements were taken manually. Following a theoretical comparison of the landmark and measurement definitions of the two surveys, and an assessment of the availability of equations to convert between different protocols and digital and manual measurements, six measurements and three proportions were identified as being able to be compared. These measurements and proportions, listed in Table 1, largely describe the overall size and proportion of the subjects.

Table 1 Measurements and proportions compared in this study.

Measurement Name (using the ANSUR protocol terminology)
Stature
Sitting height
Mass
Waist circumference
Buttock circumference
Buttock-knee length
Body mass index
Sitting height/Stature ratio
Waist circumference/Hip circumference ratio

2.4 Statistical Analysis

The statistical analyses were performed using version 9 of Statistica (Statsoft Inc., Tulsa, Oklahoma, USA). As the distributions for each dimension were approximately normal and the number of subjects in each group was large, Student's t-test was used to compare the datasets. However, if the variances of the two groups were found to be significantly different using Levene's test, Welch's t-test was used to compare the groups. To account

for the multiple comparisons significance was set at $p < 0.01$. The magnitudes of the differences between the two groups were assessed using Cohen's d, with the pooled standard deviation used for the calculation of d. Magnitudes of 0.2, 0.5 and 0.8 were interpreted as small, medium and large effect sizes, respectively.

3. Results

Table 2 lists the mean values, standard deviations and the results of the statistical comparisons for each anthropometric dimension and proportion for the MIS 872 and ANSUR datasets. Four out of six anthropometric dimensions were found to be significantly different: mass, stature, sitting height, waist circumference, and buttock circumference. In addition, one of the three proportions, sitting height/stature ratio, was found to be statistically significantly different. On average, the ADF aircrew were 2.9 kg heavier (d = 0.27, effect size small) than the ANSUR personnel, 48 mm taller (d = 0.75, effect size medium), and had a sitting height 16mm (d = 0.46, effect size small) greater. In addition, the ADF aircrew had on average a 17 mm larger waist circumference (d = 0.23, effect size small) and a 21 mm larger buttock circumference (d = 0.36, effect size small). The ADF aircrew also had a greater sitting height/stature ratio (d = 0.37, effect size small). The differences between the two groups for buttock-knee length, body mass index and waist/hip ratio were found to be not significant.

Figure 1 shows plot of key cockpit design dimensions buttock-knee length and sitting height. The blue (MIS 872 subjects) and red (ANSUR subjects) ellipses enclose 95 percent of the respective subjects (a typical accommodation level specified for vehicle design). The area of the blue ellipse outside of the red ellipse is highlighted in green. The size of the two ellipses is very similar with the blue ellipse slightly higher than the red ellipse reflecting the longer torsos of the ADF subjects. Figure 2 shows a plot of the dimensions of stature and mass. The blue (MIS 872 subjects) and red (ANSUR subjects) ellipses enclose 95 percent of the respective subjects. Again, the area of the blue ellipse outside of the red ellipse is highlighted in green. On average, the ADF personnel are both taller and heavier than their US counterparts. While the variance of mass is similar for both groups, the variation in stature is greater for the ANSUR subjects. It is likely that a significant sub-sample (green area in Figure 1 and Figure 2) of the MIS 872 subjects could experience issues with equipment designed using the ANSUR dataset.

Table 2 Statistical comparison of male ADF aircrew and male ANSUR personnel. A positive value for Cohen's d means that the mean value for the ADF subjects is greater than the mean value for the ANSUR subjects. The rating describes the qualitative size of the effect.

Body Dimension	Survey	n	Mean	SD	p	Cohen's d	Rating
Mass (kg)	ADF	155	81.4	10.3	0.002	0.27	Small
	ANSUR	1774	78.5	11.1			
Stature (mm)	ADF	155	1803	60	< 0.001	0.75	Moderate
	ANSUR	1774	1756	67			
BMI (kg/m^2)	ADF	155	25.0	2.81	0.096	-0.14	Trivial
	ANSUR	1774	25.4	3.00			
Sitting height/Stature ratio	ADF	155	0.516	0.013	< 0.001	0.37	Small
	ANSUR	1774	0.521	0.014			
Sitting height (mm)	ADF	155	930	34	< 0.001	0.46	Small
	ANSUR	1774	914	36			
Buttock-knee length (mm)	ADF	93	621	28	0.157	0.16	Trivial
	ANSUR	1774	616	30			
Waist circumference (mm)	ADF	238	857	76	0.001	0.23	Small
	ANSUR	1774	840	74			
Buttock circumference (mm)	ADF	238	1005	56	< 0.001	0.36	Small
	ANSUR	1774	984	62			
Waist/Hip ratio	ADF	238	0.852	0.049	0.668	0.00	Trivial
	ANSUR	1774	0.853	0.042			

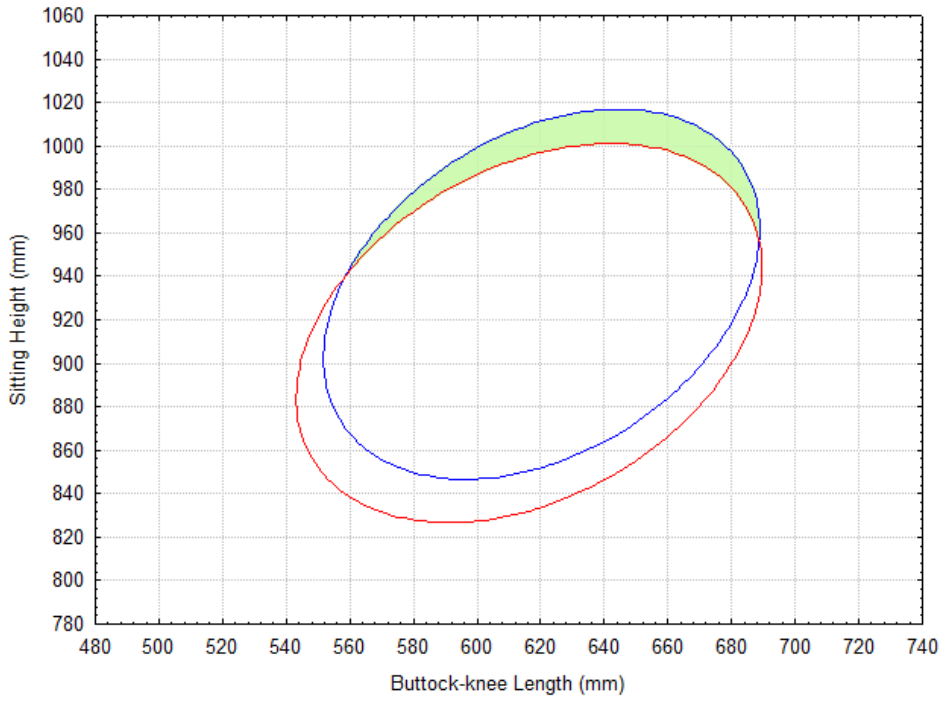

Figure 1 Plot of 95 percent ellipses for buttock-knee length versus sitting height (blue - MIS 872, red - ANSUR).

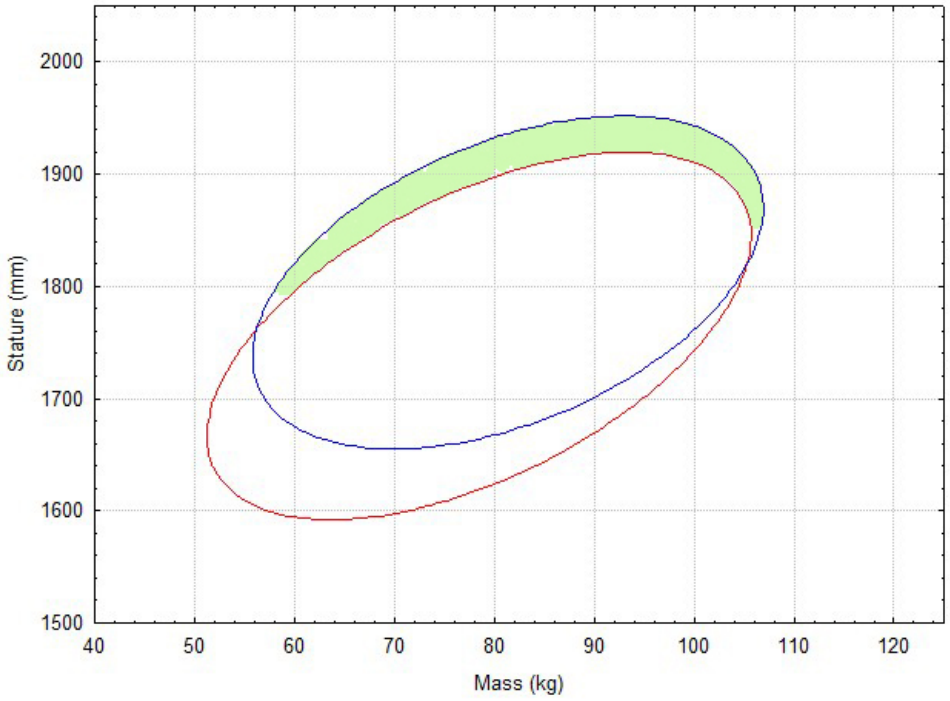

Figure 2 Plot of 95 percent ellipses for mass versus stature (blue - MIS 872, red - ANSUR).

4. Discussion

Most aircraft that the ADF acquire are designed using anthropometric data from overseas military populations, and for many acquisitions the aircraft's design has been guided by US military anthropometric data. The most recent large scale survey of a US military population for which the data is readily available was conducted in 1988. The most recent survey of the ADF aircrew population was conducted in 2004-5. The goal of this report was to compare the size and proportions of ADF aircrew and ANSUR subjects. Following a comparison of the protocols used for the two surveys and the availability of equations to convert between digital and manual measurements and different measurement protocols, it was found that six measurements and three proportions were comparable.

It was found that, on average, the Australian aircrew were 48 mm taller, had a sitting height larger by 16 mm, and were 2.9 kg heavier. The Australian subjects also had larger waists (mean girth difference 17 mm) and hips (mean girth difference 21 mm). In addition, it was found that the sitting height/ stature ratio was significantly larger for the ADF personnel. Differences in buttock-knee length, waist/hip ratio and body mass index were found to be trivial.

The differences observed in the dimensions of the two groups are most likely due to the contributions of several factors. Firstly, the ANSUR survey was conducted 17 years before the MIS 872 survey. Humans have, in general, been growing larger over the last century with increases in stature of adults of up to 3 cm/decade observed overseas and an increase of 1 cm/decade typical for many western countries (Cole, 2003). A study examining the secular changes of US Army male personnel using data from two time points (1966 and 1988) found that male personnel were growing taller at rates of up to 1.5 cm/decade (Greiner and Gordon, 1990). As a result of the significant changes in the size and shape of male and female personnel, the US Army is currently completing a survey of male and female US Army personnel (called ANSUR II). The US Army plan to measure over 12,000 male and female personnel, taking 94 manual measurements on each subject, as well as scans of the head, feet and whole body (Accetta, 2010).

The second factor is the differing ethnic mix of the two groups. The two major groups that make up the ANSUR dataset are European Americans, who make up 65% of the dataset and African Americans, who make up nearly 26% of the ANSUR dataset. In contrast, ADF aircrew are anecdotally largely of European ancestry. While the mean height of the European American and African American subjects is not significantly different ($p = 0.16$), the African subjects have significantly longer legs ($p < 0.001$) and a significantly shorter torso ($p < 0.001$) than their European American counterparts. The mean buttock-knee length for the African-American subjects is on average 630 mm, which is 17 mm longer than the European American subjects and 9 mm longer than the ADF aircrew. The mean sitting height for the African American subjects is 891 mm, which is 33 mm less than the European American subjects and 39 mm less than the ADF aircrew.

A third factor concerns the different anthropometric recruitment standards for the ADF aircrew (see Table 3) and US Army (see Table 4). To become ADF aircrew personnel must

be between 163 and 193 cm tall, have a sitting height less than 100 cm (a 95 cm maximum applies to Army aviators[3]), buttock-knee length less than 67 cm and a buttock-heel length[4] less than 122 cm (Department of Defence, 2013). Aircrew must also have a body mass index between 18.5 and 29.9 kg/m^2. In addition, pilots of ejection seat aircraft must weigh between 55 and 105 kilograms. Male US Army recruits must be between 152 and 203 cm tall and lie within age-dependent body weight limits (US Army, 2006). For example, male personnel 178 cm tall between the ages of 28 and 39 must weigh between 60 and 86 kg. A comparison of the accession standard for ADF aircrew with a survey of the potential recruit population (in this case, Australian males 18-30 years old with a year 12 pass) indicates that very few young Australian men would lie outside of these anthropometric limits. For example, the lower bound for stature is less than the first percentile for young Australian men and the upper bound is at the 98th percentile level. Similarly, the cut-off limits for sitting height and buttock-knee length are at the 98th percentile level. In addition, the weight limits are at the first percentile and 98th percentile levels. The body mass index recruitment standards for the US Army are more stringent than the Australian standard so it would be reasonable to assume the Australian aircrew would be heavier. For example, for US Army males 21 to 27 years old the upper limit for BMI is approximately 26.5 kg/m^2, compared to 29.9 kg/m^2 for Australian aircrew. While the recruitment standards are rigidly enforced, personnel in both groups may have BMI values that exceed these limits (Defence Health Service, 2002, US Army, 2006). This, in part, explains why there is no significant difference in the BMI of both groups. On average, the Australian aircrew are 47 mm taller than the ANSUR personnel, even though the maximum height for US Army personnel is 2030 mm, which is 90 mm larger the Australian maximum. Given this, it could be expected the difference in stature between the two groups would not be as great as that observed. However, the height cut-off for ADF aircrew is 26 mm greater than the 99th percentile value of stature for ANSUR males so the upper height limit for aircrew is unlikely to be a factor in the observed difference in stature. Gordon and Friedl (1994) reported that none of the US Army accession requirements eliminated more than two percent of the civilian population based on a comparison to the National Health and Nutrition Examination (NHANES) II survey anthropometric dataset. Given this, it is likely accession and retention standards only play a minor role (if any) in any differences observed between the two groups.

[3] In 2005 the maximum sitting height for Army aviators was 100 cm.
[4] Neither the ADF aircrew survey or ANSUR survey measured buttock-heel length.

Table 3 Anthropometric recruitment standard for ADF aircrew. All units are centimetres unless listed otherwise.

Measurement	Minimum	Maximum
Stature	163	193
Sitting Height (RAAF & Navy)	No minimum	100
Sitting Height (Army)	No minimum	95
Buttock-knee length	No minimum	67
Buttock-heel length	No minimum	122
Mass (ejection seat aircraft only)	55 kg	105 kg
Body Mass Index	18.5 kg/m^2	29.9 kg/m^2

Table 4 Recruitment standard for US Army male personnel.

Stature (cm)	Minimum mass (kg)	Maximum mass (kg) for each age group			
		17 - 20	21 - 27	28 - 39	> 40
152	44	60	62	63	64
155	45	62	64	65	66
157	47	64	65	67	68
160	49	66	68	70	70
163	50	68	70	72	73
165	52	70	72	74	75
168	53	73	74	76	77
170	55	75	77	79	80
173	57	77	79	81	82
175	58	80	81	84	85
178	60	82	84	86	87
180	62	84	86	88	90
183	64	86	89	91	92
185	65	89	91	93	95
188	67	91	94	96	97
191	69	94	96	99	100
193	71	96	99	101	103
196	73	99	101	104	105
198	75	101	104	107	108
201	76	104	107	110	111
203	79	106	109	112	114

4.1 Implications for Acquisitions

Given the ADF aircrew are significantly taller (48 mm taller on average, effect size moderate) than the ANSUR personnel and also have a significantly greater sitting height (16 mm larger on average, effect size small) it is possible that aircraft designed using the

ANSUR dataset will result in number of taller ADF aircrew experiencing clearance issues with the aircraft structures (for example, the canopy). It is possible that the MIS 872 subjects enclosed in the green area in Figure 1 (plot of key cockpit dimensions buttock-knee length and sitting height) may experience clearance issues if the workstation was designed using the ANSUR dataset and tight tolerances were specified. Figure 2 (plot of stature versus mass for both groups) also illustrates the potential for any item designed using the ANSUR dataset to potentially result in accommodation issues for a significant number of ADF aircrew. Many ADF aircraft have long service lives, for example the DHC-4 Caribou was in service with the ADF for 45 years. Given the increasing size of ADF aircrew (Tomkinson et al., 2010), any accommodation issues caused by the mismatch between the size of ADF aircrew and the design limits based on the ANSUR data may be exacerbated over the vehicle's lifetime.

4.2 Limitations of Analysis

Based on a theoretical comparison of the anthropometric protocols of the two groups, and the availability of equations to convert between measurements taken manually and digitally, six dimensions and three proportions were comparable in this study. The measurements and proportions largely describe the overall size and shape of the personnel. However, these measurements and proportions do not fully describe the subjects. For example, no head or face dimensions were comparable. Thus, we cannot draw any conclusions about the fit of protective equipment such as helmets and respirators. Furthermore, there was insufficient data on female ADF aircrew[5] to enable a statistical comparison to the female ANSUR subjects.

The survey data collected as part of MIS 872 is now eight years old. A recent analysis of ADF aircrew secular trends found that aircrew are growing taller at a rate of 0.74 cm per decade and heavier by 1.54 kg per decade (Tomkinson et al., 2010), so this dataset may not accurately reflect the size and shape of current aircrew. Furthermore, the MIS 872 dataset has a number of shortcomings. Firstly, no Army aircrew were measured and only a limited number of Royal Australian Navy aircrew were measured. Secondly, a number of key measurements required to support the assessment and design of aircraft were not taken on some or all of the MIS 872 subjects (for example, buttock-knee length; shoulder height, sitting; and eye height, sitting). Lastly, due to a range of issues (for example, a number of subjects were not scanned in the correct posture) a number of measurements could not be reliably extracted from the scans. Given this increase in size of aircrew, along with the limitations of the MIS 872 data, a new survey of aircrew is needed to ensure the necessary data are available to support the upgrading of existing aircraft and the acquisition of new aircraft.

[5] Females represent approximately five percent of total ADF aircrew population.

4.3 Recommendations

The following recommendations are made:

1. A comprehensive survey of ADF aircrew be conducted to ensure data are available to support future acquisitions and upgrades of vehicles and the acquisition of clothing and protective equipment. Ideally, this survey would use three dimensional laser scanning technology to enable additional measurements to be extracted at a later date.

2. When the data from the ANSUR II survey is released a statistical comparison is made between the updated US Army data and the ADF aircrew data.

3. Where possible, a statistical comparison should be made between the ADF aircrew anthropometric data and overseas data commonly used for the design of military clothing, equipment and vehicles.

5. Concluding Remarks

Typically the aircraft that the ADF acquires are designed using anthropometric data describing overseas military populations, with the data typically from a US survey. The US Army 1988 survey dataset (the most recently conducted comprehensive survey of the US military) is frequently used for the design of new vehicles (for example, the Joint Strike Fighter) and equipment. A comparison of the size and proportions of the ADF aircrew and US Army personnel showed that there were some significant differences in the size and shape of ADF aircrew and US Army personnel. To ensure aircrew accommodation is maximised for future acquisitions it is recommended that a comprehensive anthropometric survey of ADF aircrew be conducted.

6. Acknowledgements

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4. AUTHOR(S)

Peter Blanchonette and Adrian Smith

5. CORPORATE AUTHOR

DSTO Defence Science and Technology Organisation
506 Lorimer St
Fishermans Bend Victoria 3207 Australia

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19. ABSTRACT

Most aircraft that the Australian Defence Force (ADF) acquire are designed using anthropometric data from overseas populations. Often, the 1988 US Army dataset is used. A comparison of the size of the ADF aircrew and US Army personnel showed that there were significant differences in the size and shape of ADF aircrew and US Army personnel. Given these size differences, vehicles designed using the US Army dataset may result in suboptimal accommodation rates for ADF aircrew. The ADF aircrew dataset has a number of issues which limit its use. It is recommended a comprehensive survey of aircrew is conducted.